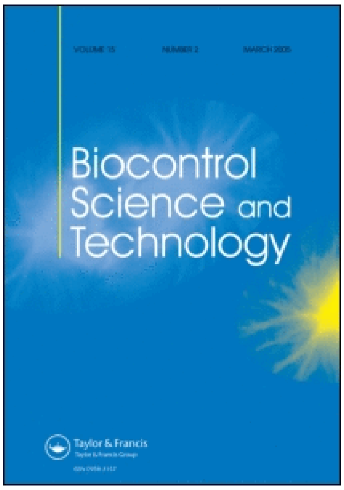
This article was downloaded by: *[USDA National Agricultural Library]*
On: *13 May 2009*
Access details: *Access Details: [subscription number 908592637]*
Publisher *Taylor & Francis*
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Biocontrol Science and Technology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713409232

Should the mirid, Eccritotarsus catarinensis (Heteroptera: Miridae), be considered for release against water hyacinth in the United States of America?

Julie A. Coetzee [a,b]; Marcus J. Byrne [a]; Martin P. Hill [b]; Ted D. Center [c]
[a] School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, South Africa [b] Department of Zoology and Entomology, Rhodes University, Grahamstown, South Africa [c] US Department of Agriculture, Agricultural Research Service, Invasive Plant Research, Laboratory, Fort Lauderdale, FL, USA

Online Publication Date: 01 January 2009

To cite this Article Coetzee, Julie A., Byrne, Marcus J., Hill, Martin P. and Center, Ted D.(2009)'Should the mirid, Eccritotarsus catarinensis (Heteroptera: Miridae), be considered for release against water hyacinth in the United States of America?',Biocontrol Science and Technology,19:1,103 — 111

To link to this Article: DOI: 10.1080/09583150802661057

URL: http://dx.doi.org/10.1080/09583150802661057

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Biocontrol Science and Technology,
Vol. 19, No. 1, 2009, 103–111

Taylor & Francis
Taylor & Francis Group

Should the mirid, *Eccritotarsus catarinensis* (Heteroptera: Miridae), be considered for release against water hyacinth in the United States of America?

Julie A. Coetzee[a,b]*, Marcus J. Byrne[a], Martin P. Hill[b] and Ted D. Center[c]

[a]*School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, 11 Johannesburg, South Africa;* [b]*Department of Zoology and Entomology, Rhodes University, Grahamstown, South Africa;* [c]*US Department of Agriculture, Agricultural Research Service, Invasive Plant Research, Laboratory, Fort Lauderdale, FL, USA*

(Received 16 July 2008; returned 28 August 2008; accepted 2 December 2008)

Downloaded By: [USDA National Agricultural Library] At: 13:21 13 May 2009

Between one and seven biological control agents have been released against water hyacinth (*Eichhornia crassipes* (Mart.) Solms) in at least 30 countries, with varied success. A mirid, *Eccritotarsus catarinensis* (Carvalho) (Heteroptera: Miridae), the most recent agent released, is damaging to the plant on the African continent. It could be useful in the USA where water hyacinth remains a problem, but its introduction remains in doubt because during host specificity trials, it developed on *Pontederia cordata* L. (pickerelweed), indigenous to the USA. However, it did not establish on pickerelweed monocultures during South African field trials, and only light spillover feeding occurred where the two plants coexisted suggesting that the use of *P. cordata* as a host is a laboratory artefact and it may be suitable for use in the USA, if its thermal physiology allows establishment. We reran models developed for South Africa using CLIMEX to predict whether the mirid will establish where water hyacinth and pickerelweed co-occur, but not where pickerelweed occurs in the absence of water hyacinth. The models suggest that the mirid's distribution will be limited by cold winter temperatures and insufficient thermal accumulation to the southern states of the USA, within the main distribution of water hyacinth. Even though some spillover feeding on pickerelweed might result where the two plants co-occur, the risk of population level effects seems minimal and the risk to more northern pickerelweed negligible. The benefits, including improved habitat for pickerelweed, associated with further suppression of water hyacinth, outweigh the minimal risk of collateral damage to pickerelweed.

Keywords: climate matching; pre-release evaluation; pickerelweed; host specificity, realised host range

Introduction

Biological control agents against water hyacinth (*Eichhornia crassipes* (Mart.) Solms), one of the world's worst aquatic weeds, have been released in at least 30 countries worldwide (Julien and Griffiths 1998). The most successful are the weevils, *Neochetina bruchi* Hustache (Coleoptera: Curculionidae) and *N. eichhorniae* Warner (Coleoptera: Curculionidae), and the moth *Niphograpta albiguttalis* (Warren) (=*Sameodes albguttalis* (Warren)) (Lepidoptera: Pyralidae), which have established

*Corresponding author. Email: julie.coetzee@ru.ac.za

ISSN 0958-3157 print/ISSN 1360-0478 online
© 2009 Taylor & Francis
DOI: 10.1080/09583150802661057
http://www.informaworld.com

throughout the world where biological control against water hyacinth has been implemented (Julien and Griffiths 1998).

Although these agents have been at least partially successful, their effects are spatially and temporally variable such that water hyacinth still causes problems in many regions, including areas in the USA (Center, Dray, Jubinsky, and Grodowitz 1999a) and South Africa (Hill and Olckers 2000). More consistent results might be obtained by additional herbivore pressure which calls for the evaluation of additional control agents (Stanley and Julien 1999). One such agent against water hyacinth is the mirid, *Eccritotarsus catarinensis* (Carvalho) (Heteroptera: Miridae), which was released in South Africa during 1996 (Hill, Cilliers, and Neser 1999). They found that *E. catarinensis* has potential as a control agent of water hyacinth in South Africa due to its host specificity and because it has long-lived, mobile adults that obviously damage the plant. The four nymphal instars and the adults feed gregariously. Their feeding causes chlorosis of the foliage due to extraction of chlorophyll from the palisade parenchyma, which ultimately leads to death of the afflicted leaves (Hill et al. 1999). This mirid has been released in South Africa at no less than 18 sites since 1996 (Hill et al. 1999), and has established at least 15 sites. Subsequent evaluations have demonstrated that it impacts water hyacinth growth (Coetzee, Byrne, and Hill 2007a) and competitive ability (Coetzee, Center, Byrne, and Hill 2005; Ajuonu, Byrne, Hill, Neuenschwander, and Korie 2008), by reducing the plant's overall vigour.

Eccritotarsus catarinensis has also been released in Zimbabwe, Zambia, Malawi, Benin and China, but has only established in Malawi. It was, however, rejected for release in Australia because of possible damage to populations of native *Monochoria vaginalis* (Burman f.) Kunth. (Pontederiaceae) (Stanley and Julien 1999). The mirid is also being considered for release in the USA, but host specificity data from laboratory trials showed that native American pickerelweed (*Pontederia cordata* L.), an important littoral plant of waterways in the USA, may be at risk because feeding, oviposition and nymphal development were recorded on several species in the Pontederiaceae, including pickerelweed during host range studies in South Africa (Hill et al. 1999). However, field trials in South Africa suggest that this risk is minimal. At high population densities, the mirid spills over from water hyacinth onto pickerelweed when both species grow in proximity to one another. By definition, this 'spillover' feeding is temporary as it is the result of large population densities of mirids feeding on a suboptimal host (Louda, Pemberton, Johnson, and Follett 2003), and even then, damage to pickerelweed is much less than on water hyacinth (Hill et al. 2000). More importantly, the mirids fail to persist on pickerelweed when water hyacinth is absent (Coetzee, Byrne, and Hill 2003).

Even though the mirid is both damaging and poses no threat to pickerelweed, it would be futile to release it in the USA if it is not physiologically capable of establishing at water hyacinth infested sites. Investigation of the mirid's thermal physiology predicted that cold winter temperatures would limit the distribution of this insect in South Africa to tropical and subtropical regions (Coetzee, Byrne, and Hill 2007b). This should also have a significant limiting effect on the establishment of *E. catarinensis* in the USA, particularly in the more northern states where water hyacinth is restricted in its northerly distribution by winter temperatures (Gopal 1987). We therefore wanted to determine whether the mirid will be physiologically restricted to the warmer areas in the southern USA where water hyacinth is a

Downloaded By: [USDA National Agricultural Library] At: 13:21 13 May 2009

problem, and excluded from the northern areas where pickerelweed occurs but where water hyacinth is absent. We used degree-day modelling and climate matching to investigate the potential distribution of *E. catarinensis* in the USA to further predict the potential consequences of releasing *E. catarinensis* in the USA.

Materials and methods

This study reran models developed for predicting the distribution of *E. catarinensis* in South Africa, to predict its distribution in the USA, based on thermal physiological parameters determined in a previous study (Coetzee et al. 2007b) (Table 1). We used various outputs in the 'Compare Locations' function in CLIMEX 3 (Hearne Scientific Software), which employs an inferential approach to indicate the organisms' relative weekly population response to temperature variables, using interpolated climate data (Sutherst, Maywald, and Kriticos 2007). First, a potential distribution of *E. catarinensis* in the USA was created using the same CLIMEX parameter values generated by inserting physiological data obtained in previous experiments, including the critical thermal minimum (CTMin) and lower lethal temperature (LT_{50}) (Coetzee et al. 2007b), into the CLIMEX computer program parameter thresholds, to produce Ecoclimatic Index (EI) values for climate grid data in the CLIMEX meteorological database for the USA. This model combines growth and stress parameters to produce the EI which is a measure of the overall suitability of the climate for the target species. The EI describes the favourability of a location for a species and is scaled from 0 to 100 to represent the overall suitability of a geographical location for the propagation and persistence of the species. As such, it indicates only the gross features of a species' likely distribution (Sutherst and Maywald 1985).

Secondly, the 'Generations' output was selected to display the mean annual degree-days accumulated for each grid cell, expressed as the number of generations that the mirid could produce in a year. The reduced major axis regression method proposed by Ikemoto and Takai (2000) was used to estimate the thermal constant K and developmental threshold *t* (Table 1), parameters required by CLIMEX to calculate accumulated degree-days and number of generations.

Lastly, because mirid development is limited by cold winter temperatures in South Africa (Coetzee et al. 2007b), it is also likely to be limited by winter temperatures in the USA during which no development can occur, so the number of weeks during which positive growth can occur was calculated using the 'Weeks of positive growth index' (Weeks of GI-pos) output. The weeks of GI-pos uses the 'Growth index' (GI) to calculate the number of weeks in the year in which the GI is non-zero.

Table 1. Thermal physiological parameters of *Eccritotarsus catarinensis* (from Coetzee et al. 2007b).

Physiological parameter	Value
Rate of development (K)	342 degree-days
Developmental threshold (*t*)	10.3°C
Critical thermal minimum (CTMin)	1.2 ± 1.17°C
Lower lethal temperature (LT_{50})	-3.5°C

Downloaded By: [USDA National Agricultural Library] At: 13:21 13 May 2009

All of these maps were imported into ArcGIS 9.3 (ESRI, Redlands California) where the distribution of water hyacinth and pickerelweed in the USA were overlaid onto the models.

Results

The hypothetical distribution of *E. catarinensis* in the USA, as predicted by CLIMEX, illustrates that only the southern states have EI values high enough to allow the mirid to establish and persist (Figure 1). Locations with an EI value close to 0 are not suitable for the long-term survival of the species, while an EI greater than 30 is considered very favourable (Sutherst, Maywald, Yonow, and Stevens 1999). All of the unfavourable locations have an EI of 0, because cold stress accumulated over winter limits the potential distribution of the mirid at these locations.

Similarly, degree-day modelling indicated that *E. catarinensis* can complete at least one generation per year over most of the continental USA (up to 16 generations could occur in Florida) (Figure 2). Degree-day modelling therefore predicts that insufficient thermal summation particularly over the cold winter months will limit the mirid's distribution to the south-eastern USA, where water hyacinth occurs. In the marginal areas, there is insufficient heat over the winter months to allow the populations to build up, suggesting that transient populations may occur over the summer months only. Furthermore, the number of weeks of positive growth is highest in the south-eastern states where every week of the year is available for positive growth, while less than half the year is favourable in the north east, and no weeks are favourable in the north west (Figure 3).

Discussion

Water hyacinth is limited to the southern states of the USA by cold winters (Gopal 1987). The results presented here suggest that the mirid should be able to establish

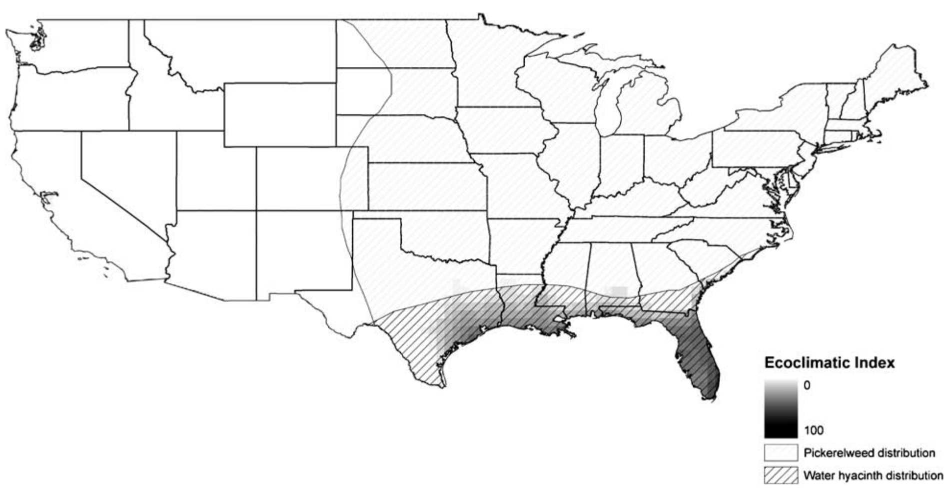


Figure 1. The potential geographical distribution of *Eccritotarsus catarinensis* in the United States of America, as fitted by the 'Ecoclimatic Index (EI)' in CLIMEX 3.

Downloaded By: [USDA National Agricultural Library] At: 13:21 13 May 2009

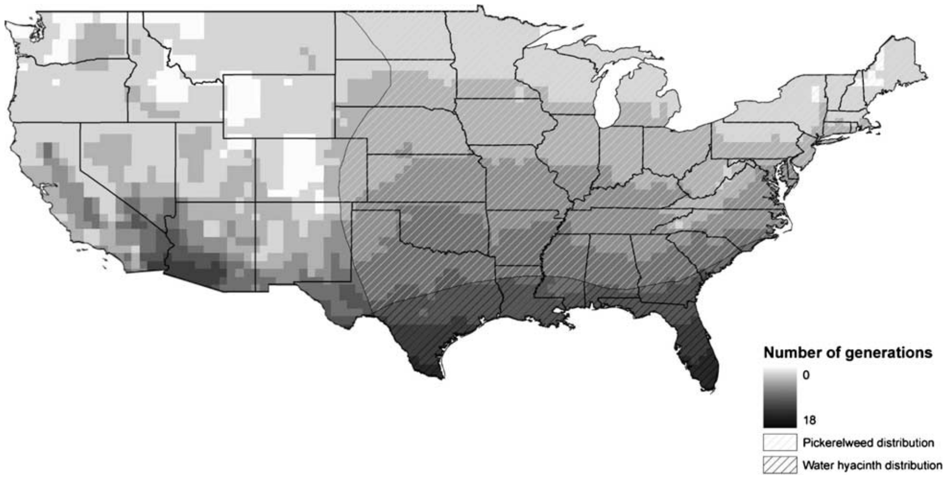


Figure 2. The number of generations that *Eccritotarsus catarinensis* can complete in a year in the United States of America, estimated from the parameters K and t obtained using the reduced major axis regression model, and modeled using the 'Generations' output in CLIMEX 3.

permanent populations throughout the range of water hyacinth in the southern USA, as the CLIMEX model generated high EI values in the south (Figure 1), and predicted it to be able to complete between eight and 16 generations in a year where water hyacinth is present (Figure 2). The mirid was originally collected from Florianopolis and Rio de Janeiro in Brazil, where a previous study predicted that it would complete 12 and 13 generations a year, respectively (Coetzee et al. 2007b). So the 16 generations predicted in Florida exceeds the number of generations predicted for those two Brazilian locations. Extremely cold winter temperatures in the USA are likely to limit *E. catarinensis* to southern states that experience milder winters, where

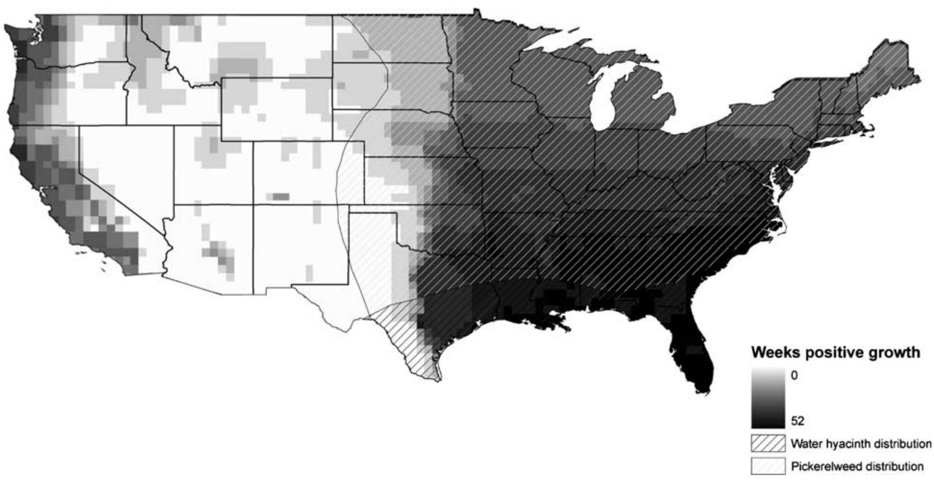


Figure 3. The number of weeks of positive growth of *Eccritotarsus catarinensis* in the United States of America, as fitted by the 'Weeks of positive growth' output in CLIMEX 3.

Downloaded By: [USDA National Agricultural Library] At: 13:21 13 May 2009

the mirid should survive through the winter. It would likely thrive in Florida and southern Texas, where every week of the year is available for positive growth. A latitudinal cut off point is predicted at 35°N, beyond which the mirid will not be able to persist, only establishing temporarily during summer months. The mirid could therefore be a useful additional control agent of water hyacinth in the USA inasmuch as it reduces water hyacinth vigor and would be able to survive during the winter in the south.

Pickerelweed has a range well beyond that of water hyacinth into the northern states, but because the CLIMEX model predicted that the mirid is unable to establish in the central and northern states of the USA due to extreme cold winters, and therefore insufficient thermal summation required to overwinter, any potential risk to pickerelweed in these states is eliminated. Furthermore, the mirid is unable to establish on pickerelweed in the field, in the absence of water hyacinth (Coetzee et al. 2003). However, spillover feeding damage to pickerelweed is still a concern where water hyacinth and pickerelweed co-occur (Hill et al. 2000). Any fear that the mirid will exterminate pickerelweed is exaggerated, however, and the transitory, light feeding that may occur on pickerelweed is unlikely to threaten the existence of this plant. Where water hyacinth and pickerelweed co-occur, herbicide operations against water hyacinth also eliminate pickerelweed, and drifting mats of water hyacinth scour the pickerelweed stands and uproot the plants, causing their destruction (Center, Van, and Hill 2001). So, improved biological control of water hyacinth would likely benefit pickerelweed.

Approximately 30% of insects introduced as weed control agents to the USA cause substantial damage to their target plants, but only 6% are able to reduce weed density sufficiently by themselves (Harris 1988). More importantly, only about three out of 95 successful agents released have caused damage to nontarget, native plants (McFadyen 1998), e.g. the weevil, *Rhinocyllus conicus* Froel. (Coleoptera: Curculionidae), released to control Eurasion thistles of the genus *Carduus* L. (Louda, Kendall, Connor, and Simberloff 1997). Clearly there are dangers inherent in releasing control agents with known broad host ranges, but the benefits associated with the release of more host specific agents need to be remembered. For instance, the weevil, *N. eichhorniae* is one of the most successful control agents released against water hyacinth in the USA, where numerous studies have documented its beneficial effects (e.g. Goyer and Stark 1984; Center and Van 1989; Grodowitz, Stewart, and Cofrancesco 1991; Center, Dray, Jubinsky, and Leslie 1999b). However, after weevil herbivory causes the collapse of water hyacinth populations in early autumn, sizable populations of adult weevils spill over onto ornamental canna (*Canna* spp.) and pickerelweed (Center 1982). It was known prior to release that the weevil could feed on pickerelweed, but that it was not a developmental host (Center 1982). The level of feeding damage by the weevil to these non-target plants is acceptable because of the associated benefits of reduction in water hyacinth.

There is usually insufficient evidence to validate the safety or risk of biocontrol because monitoring of damage by introduced control agents to non-target species is often minimal (Simberloff and Stiling 1996a). Both proponents and opponents of biocontrol recommend that extensive pre- and post-release evaluations on environmental effects of control agents be conducted to assess the risk of introduced agents (e.g. Simberloff and Stiling 1996b; Thomas and Willis 1998; McEvoy and Coombs 2000), but completing such evaluations efficiently and thoroughly is a daunting

Downloaded By: [USDA National Agricultural Library] At: 13:21 13 May 2009

prospect due to the vast amount of time and resources that they require. Moreover, releasing more and more control organisms contests the capabilities of monitoring efforts (McEvoy and Coombs 1999), in that monitoring multiple agents is difficult. While this is not an acceptable excuse not to conduct post-release evaluations, there are few examples of such analyses. Studies such as this one and its associated findings (e.g. Hill et al. 2000; Coetzee et al. 2003, 2005, 2007a) go some way to addressing these concerns in that they provide ideal opportunities to perform what many researchers have suggested, such as Louda's (2000) insights to minimise the risk of biocontrol agents. Much of the pre-release testing of *E. catarinensis*, as well as a substantial amount of post-release assessment, pertinent to its use in the USA, has been conducted on another continent, thereby providing further data regarding the need for and safety of this agent.

We therefore suggest that *E. catarinensis* be considered for release as an additional control agent of water hyacinth in the USA, inasmuch as it only reluctantly accepts pickerelweed as a host, and then only in the presence of its preferred host, water hyacinth (Hill et al. 2000). The recent determination that the mirid reduces the vigour of water hyacinth, in terms of growth and competitive ability (Coetzee et al. 2005, 2007a), and the results of this study alleviates this concern and further justifies consideration of this insect for release in the USA.

Downloaded By: [USDA National Agricultural Library] At: 13:21 13 May 2009

Acknowledgements

The Working for Water Program of the Department of Water Affairs and Forestry, South Africa, is acknowledged for its financial assistance with this project.

References

Ajuonu, O., Byrne, M., Hill, M., Neuenschwander, P., and Korie, S. (2008), 'The Effect of Two Biological Control Agents, the Weevil *Neochetina eichhorniae* and the Mirid *Eccritotarsus catarinensis* on Water Hyacinth, *Eichhornia crassipes*, Grown in Culture with Water Lettuce, *Pistia stratiotes*', *BioControl*, in press, DOI 10.1007/s10526-008-9185-6.

Center, T.D. (1982), 'The Water Hyacinth Weevils', *Aquatics*, 4, 8–19.

Center, T.D., Dray Jr, F.A., Jubinsky, G.P., and Grodowitz, M.J. (1999a), 'Biological Control of Water Hyacinth under Conditions of Maintenance Management: Can Herbicides and Insects be Integrated?', *Environmental Management*, 23 (2), 241–256.

Center, T.D., Dray, F.A., Jubinsky, G.P., and Leslie, A.J. (1999b), 'Water Hyacinth Weevils (*Neochetina eichhorniae* Warner and *N. bruchi* (Hustache)) Inhibit Water Hyacinth (*Eichhornia crassipes*) Colony Development', *Biological Control*, 15, 30–50.

Center, T.D., and Van, T.K. (1989), 'Alteration of Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms) Leaf Dynamics and Phytochemistry by Insect Damage and Plant Density', *Aquatic Botany*, 35, 181–195.

Center, T.D., Van, T.K., and Hill, M.P. (2001), 'Can Competition Experiments be Used to Evaluate the Potential Efficacy of New Water Hyacinth Biological Control Agents?', in *Biological and Integrated Control of Water hyacinth,* Eichhornia crassipes*, Proceedings of the 2nd Meeting of the Global Working Group for the Biological and Integrated Control of Water hyacinth*, *Beijing, China, 9–12 October 2000*, eds M.H. Julien, M.P. Hill, T.D. Center and D. Jianqing, Australian Centre for International Agricultural Research: Canberra, Australia, pp. 77–81.

Coetzee, J.A., Byrne, M.J., and Hill, M.P. (2003), 'Failure of *Eccritotarsus catarinensis*, a Biological Control Agent of Water Hyacinth, to Persist on Pickerelweed, a Non-target Host in South Africa, After Forced Establishment', *Biological Control*, 28, 229–236.

Downloaded By: [USDA National Agricultural Library] At: 13:21 13 May 2009

Coetzee, J.A., Byrne, M.J., and Hill, M.P. (2007a), 'Impact of Nutrients and Herbivory by *Eccritotarsus catarinensis* on the Biological Control of Water Hyacinth, *Eichhornia crassipes*', *Aquatic Botany*, 86, 179–186.

Coetzee, J.A., Byrne, M.J., and Hill, M.P. (2007b), 'Predicting the Distribution of *Eccritotarsus catarinensis*, a Natural Enemy Released on Water Hyacinth in South Africa', *Entomologia Experimentalis et Applicata*, 125, 237–247.

Coetzee, J.A., Center, T.D., Byrne, M.J., and Hill, M.P. (2005), 'The Impact of *Eccritotarsus catarinensis*, a Sap-feeding Mirid Biocontrol Agent, on the Competitive Performance of Water Hyacinth', *Biological Control*, 32, 90–96.

Gopal, B. (1987), *Water Hyacinth*, Amsterdam: Elsevier.

Goyer, R.A., and Stark, J.D. (1984), 'The Impact of *Neochetina eichhorniae* on Water Hyacinth in Southern Louisiana', *Aquatic Plant Management*, 22, 57–61.

Grodowitz, M.J., Stewart, R.M., and Cofrancesco, A.F. (1991), 'Population Dynamics of Water Hyacinth and the Biological Control Agent *Neochetina eichhorniae* (Coleoptera: Curculionidae) at a Southeast Texas Location', *Environmental Entomology*, 20, 653–660.

Harris, P. (1988), 'Environmental Impact of Weed-control Insects', *Bioscience*, 38, 542–548.

Hill, M.P., Cilliers, C.J., and Neser, S. (1999), 'Life History and Laboratory Host Range of *Eccritotarsus catarinensis* (Carvalho) (Heteroptera: Miridae), a New Potential Natural Enemy Released on Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms-Laub.) (Pontederiaceae) in South Africa', *Biological Control*, 14, 127–133.

Hill, M.P., and Olckers, T. (2000), 'Biological Control Initiatives Against Water Hyacinth in South Africa: Constraining Factors, Success and New Courses of Action', in *Proceedings of the 2nd Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth*, Beijing, China, 9–12 October 2000, eds. M.H. Julien, M.P. Hill, T.D. Center and D. Jianqing, Australian Centre for International Agricultural Research: Canberra, Australia, pp. 33–38.

Hill, M.P., Center, T.D., Stanley, J., Cordo, H.A., Coetzee, J.A., and Byrne, M.J. (2000), 'The Performance of the Water Hyacinth Mirid, *Eccritotarsus catarinensis*, on Water Hyacinth and Pickerel Weed: A Comparison of Laboratory and Field Results', in *Proceedings of the Xth International Symposium on the Biological Control of Weeds*, Bozemon, Montana, USA, 4–14 July 1999, ed. N.R. Spencer, Bozeman, MT, USA: Montana State University, pp. 357–366.

Ikemoto, T., and Takai, K. (2000), 'A New Linearised Formula for the Law of Total Effective Temperature and the Evaluation for Line Fitting Methods with Both Variables Subject to Error', *Environmental Entomology*, 29, 671–682.

Julien, M.H., and Griffiths, M.W. (1998), *Biological Control of Weeds: A World Catalogue of Agents and their Target Weeds* (4th ed.), Oxon, UK: CABI Publishing, CAB International.

Louda, S.M. (2000), '*Rhinocyllus conicus* – Insights to Improve Predictability and Minimize Risk of Biological Control of Weeds', in *Proceedings of the Xth International Symposium on the Biological Control of Weeds*, Bozemon, Montana, USA, 4–14 July 1999, ed. N.R. Spencer, Bozeman, MT, USA: Montana State University, pp. 187–193.

Louda, S.M., Kendall, D., Connor, J., and Simberloff, D. (1997), 'Ecological Effects of an Insect Introduced for the Biological Control of Weeds', *Science*, 277, 1088–1090.

Louda, S.M., Pemberton, R.W., Johnson, M.T., and Follett, P.A. (2003), 'Nontarget Effects – the Achilles' Heel of Biological Control? Retrospective analyses to reduce risk associated with biocontrol introductions', *Annual Review of Entomology*, 48, 365–396.

McEvoy, P.B., and Coombs, E.M. (1999), 'Biological Control of Plant Invaders: Regional Patterns, Field Experiments, and Structured Population Models', *Ecological Applications*, 9, 387–401.

McEvoy, P.B., and Coombs, E.M. (2000), 'Why Things Bite Back: Unintended Consequences of Biological Weed Control', in *Nontarget Effects of Biological Control*, eds. P.A. Follett and J.J. Duan, Boston, MA, USA: Kluwer Academic Publishers, pp. 167–194.

McFadyen, R.E.C. (1998), 'Biological Control of Weeds', *Annual Review of Entomology*, 43, 369–393.

Simberloff, D., and Stiling, P. (1996a), 'How Risky is Biological Control?', *Ecology*, 77, 1965–1974.

Simberloff, D., and Stiling, P. (1996b), 'Risks of Species Introduced for Biological Control', *Biological Conservation*, 78, 185–192.

Stanley, J.N., and Julien, M.H. (1999), 'The Host Range of *Eccritotarsus catarinensis* (Heteroptera: Miridae), a Potential Agent for the Biological Control of Water Hyacinth (*Eichhornia crassipes*)', *Biological Control*, 14, 134–140.

Sutherst, R.W., and Maywald, G.F. (1985), 'A Computerised System for Matching Climates in Ecology', *Agriculture, Ecosystems and Environment*, 13, 281–299.

Sutherst, R.W., Maywald, G.F., Yonow, T., and Stevens, P.M. (1999), *Climex: Predicting the Effects of Climate on Plants and Animals*, Climex 1.1 User Guide, Victoria: CSIRO Publishing.

Sutherst, R.W., Maywald, G.F., and Kriticos, D.J. (2007), CLIMEX Version 3: User's Guide, Hearne Scientific Software Pty Ltd., www.hearne.com.au.

Thomas, M.B., and Willis, A.J. (1998), 'Biological Control – Risky but Necessary?', *Trends in Ecology and Evolution*, 13, 325–329.

Downloaded By: [USDA National Agricultural Library] At: 13:21 13 May 2009